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CONSIDERATION OF SOME AERODYNAMIC CHARACTERISTICS DURING TAKE-OFF AND LANDING OF JET AIRPLANES

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CONSIDERATION OF SOME AERODYNAMIC CHARACTERISTICS DURING TAKE-OFF AND LANDING OF JET AIRPLANES

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SUMMARY

In view of the transition from propeller-driven to jet transports, a study was made to determine some of the important differences in the aerodynamic characteristics during take-off and landing. These differences were primarily associated with the absence of propeller slipstream over the wing and the attendant effects on lift. The considerations were limited only to lift-drag relations and did not include such possible related factors as noise, heating, foreign-matter ingestion, or ability to obtain thrust reversal. Speed and attitude may require closer attention for jet transports than for propeller-driven transports. Jet transports, by application of a system of lift augmentation, can have a lift-coefficient response with power on similar to that which has provided an operational margin for propeller-driven transports.

INTRODUCTION

In view of the transition from propeller-driven to jet transports, a study was made to determine certain important differences in the aerodynamic characteristics in the critical area of take-off and landing operations. These differences are primarily associated with the absence of propeller slipstreams over the wing and the attendant effects on lift. The present paper presents some results from wind-tunnel tests and implications from the lift-drag effects in relation to differences in operating techniques of jet and propeller-driven transports.

The results of some wind-tunnel tests of a jet-augmented-flap arrangement are also presented with the view that such a device might be considered for providing future jet transports with lift increments due to power similar to the slipstream effect of propeller-driven transports, should experience with present jet transports indicate the need for this characteristic.

SYMBOLS

C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_T	thrust coefficient, $\frac{T}{qS}$
T	thrust, lb
W	weight, lb
q	dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft
ρ	mass density of air, 0.002378 slug/cu ft
V	velocity, knots
α	angle of attack, deg
δ_f	flap deflection, deg
V_2	take-off velocity, $1.15 \times$ Minimum power-off steady flight speed for take-off configuration (See ref. 1.)
S	wing area, sq ft

DISCUSSION

The data used for these considerations were obtained in wind-tunnel tests at the Ames Research Center (for example, see ref. 2) and in the Langley 7- by 10-foot tunnels on models such as those shown in the plan forms given in the figures.

Take-Off Maneuver

The effect of power on lift coefficient for the propeller-driven and jet transports is presented in figures 1 and 2, respectively, where C_L is plotted against α. Lift coefficient at a given angle of attack increases with the application of power for the propeller-driven transport; this increase, of course, is attributed primarily to propeller-slipstream effects on the wing lift. During take-off for the airplane being considered, the thrust reaction in the lift direction is negligible. For the jet transport the power-off and power-on curves coincide because the jet makes little or no contribution to the lift coefficient through augmentation effects and the thrust-reaction component to lift is also negligible. The magnitude of lift coefficient corresponding to V_2, the take-off speed, as determined from civil air regulations (ref. 1) is shown by the horizontal dashed line.

For the jet airplane, V_2 is relatively close to the maximum lift coefficient available, either with power off or on, indicating little margin available in attitude or speed. This fact is especially critical for the jet transport because the airplane after acceleration for take-off at low angles of attack must be rotated to obtain take-off lift. This presents the possibility of overrotation into the high-drag or stall region. However, for the propeller-driven airplane, although the take-off speed V_2 is relatively close to the maximum lift coefficient with power off, a fairly large reserve in lift coefficient is available in operation with power on. With the added lift due to slipstream the angle of attack required for the transport to lift off at V_2 is less than without slipstream and the rotation required is therefore less than for the jet transport. Although these characteristics are not formally written into the civil air regulations, they do provide an operational margin for propeller-driven transports and are lacking for jet transports.

Coupled with the greater possibility of running out of lift coefficient on the jet airplane is the possible loss in acceleration or climb because of high drag at the stall angle-of-attack region. This is illustrated in figures 3 and 4 which show curves for the estimated thrust available and the required thrust for a propeller-driven and a jet transport, respectively, given in terms of the nondimensional parameter T/W or thrust divided by weight. For the propeller-driven transport the application of constant engine power provides a reserve in minimum speed of about 35 knots below V_2 with as much or more thrust increment available for climb as at the take-off speed V_2. Very little speed margin is indicated for the jet airplane because power has a negligible effect on the lift available for minimum speed. In addition, at speeds below V_2, the increment between thrust available and thrust required falls off rapidly with the result that ability to climb is rapidly reduced. These considerations indicate that careful maneuvering for lift-off and climb should be exercised for the jet transport. The use of an angle-of-attack indicator should be of considerable assistance in this regard. Recent civil air regulations permit the use of a standby source of power such as rocket engines which could widen the operation margin.

Another possible solution to the narrower working speed and attitude range of the jet transport is to increase the maximum lift coefficient by the use of leading-edge devices which extend the lift coefficient to higher angles of attack and, at the same time, reduce the thrust required by the delay of air-flow separation. This design consideration in conjunction with the ground attitude limitation might prevent the airplane from being rotated above the maximum lift coefficient. However, this design consideration would probably be compromised to some extent because additional weight inevitably appears when lift becomes available, resulting in V_2 occurring at a higher lift coefficient which is again relatively close to maximum lift coefficient.

Another possible solution to this problem would be to have a lift-coefficient curve with power for the jet transport similar to that for the propeller-driven transport. This solution suggests some utilization of the jet-propulsion system to increase the lift on the wing such as the application of lift augmentation by means of a jet flap. However, it should be emphasized that the purpose of the lift augmentation being considered is to provide an operational margin and not to provide lift for shorter take-off and landing as in the more usual sense. Under this circumstance ratios of thrust to weight of the order of that on current jet airplanes can be considered.

Figure 5 shows cross-sectional views of several possible jet-flap arrangements that could be used to provide the lift augmentation. For the power-on conditions the jet engine exhaust is directed over the flap. For the power-off conditions a double-slotted-flap configuration is used in order to provide the highest lift possible with engines out. Details of the lift-augmentation systems are given in references 3, 4, and 5. For the present analysis, lift and thrust curves were determined for the internal-flow system since these data were available at the low flap deflections used for take-off. The flap was full span and deflected 30°. Ground effect was not included, but the effects are small for the conditions considered. It should also be emphasized that choice of the lift-augmentation system and ease or difficulty of installation would be affected by many considerations such as noise, structural integrity with heat, foreign-matter ingestion, and possible use of thrust reversal in the system.

Lift-coefficient curves for the power-off and power-on conditions of the internal arrangement of figure 5 are shown in figure 6. The effect of the lift augmentation (in this case for a value of thrust-weight ratio of 0.22) is similar to that of the propeller-driven transport.

The curves for thrust available and thrust required for the jet transport with the lift-augmentation system are shown in figure 7. The thrust-required curve with lift augmentation extends to lower speeds and the rate of reduction of the increment between available and required thrust drops off more slowly at the lower speeds than for the power-off condition. A comparison of figure 6 with figure 1 and figure 7 with figure 3 indicates that the lift-augmentation system of the jet transport provides an operational margin in lift (or speed) and attitude somewhat similar to that of the propeller-driven transport.

Landing Approach

The effect of power in providing lift characteristics for a jet transport similar to those that have been found of considerable benefit for a propeller-driven transport is shown by a comparison of figures 8 and 9. The lift coefficient is plotted as a function of thrust coefficient for the airplanes at constant α in a 3° glide in the landing-approach condition. Initial trim conditions of C_L and C_T for the two airplanes are noted by the circular symbols.

For the propeller-driven transport (fig. 8), increased thrust coefficient also results in increased lift coefficient because of the effect of propeller slipstream. For the jet transport (fig. 9) without lift augmentation, no change in lift accompanies a change in thrust; therefore, airplane response, such as in a landing wave-off or in a correction to glide path, will probably be not so rapid as that for the propeller-driven transport. Through the use of the lift-augmentation system, the lift-coefficient response with power on can be made similar to that of the propeller-driven transport.

CONCLUDING REMARKS

A study was made to determine certain differences in the aerodynamic characteristics during take-off and landing of jet and propeller-driven transports. Because of the absence of propeller-slipstream effects on wing lift, jet transports probably have less operational margin than do propeller-driven transports. If the need arises, jet transports, by the application of lift augmentation, can have a lift-coefficient response with power on similar to that which experience with propeller-driven transports has indicated desirable. The considerations are limited only to lift-drag relations and do not include such possible related factors as noise, heating, foreign-matter ingestion, or ability to obtain thrust reversal.

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National Aeronautics and Space Administration,
Langley Field, Va., April 14, 1959.

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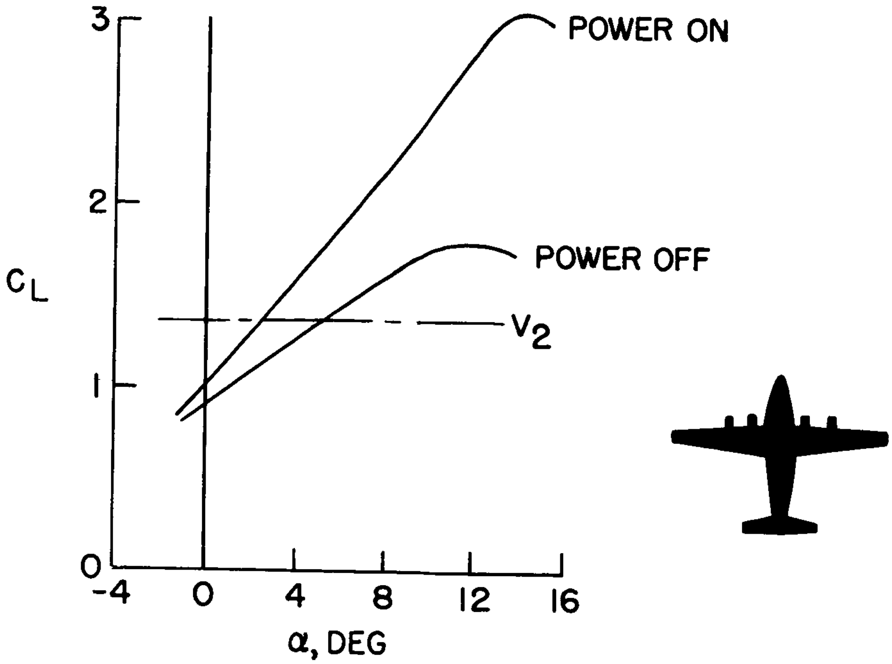

Figure 1.- Effect of power on lift coefficient for propeller-driven transport. Take-off condition; $\delta_f = 20^\circ$.

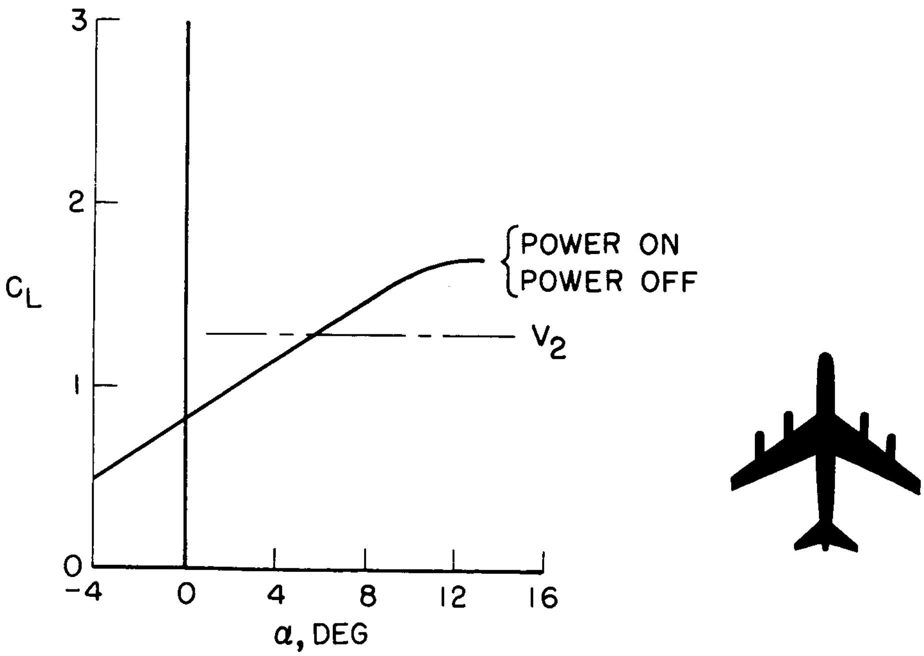

Figure 2.- Effect of power on lift coefficient for jet transport. Take-off condition; $\delta_f = 30^\circ$.

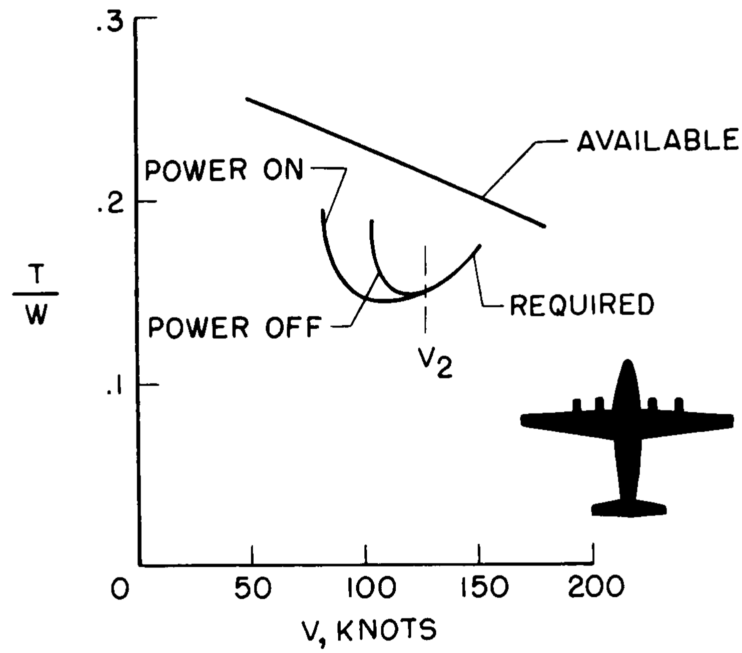

Figure 3.- Thrust variation for propeller-driven transport. Take-off condition; $\delta_f = 20^{\circ}$.

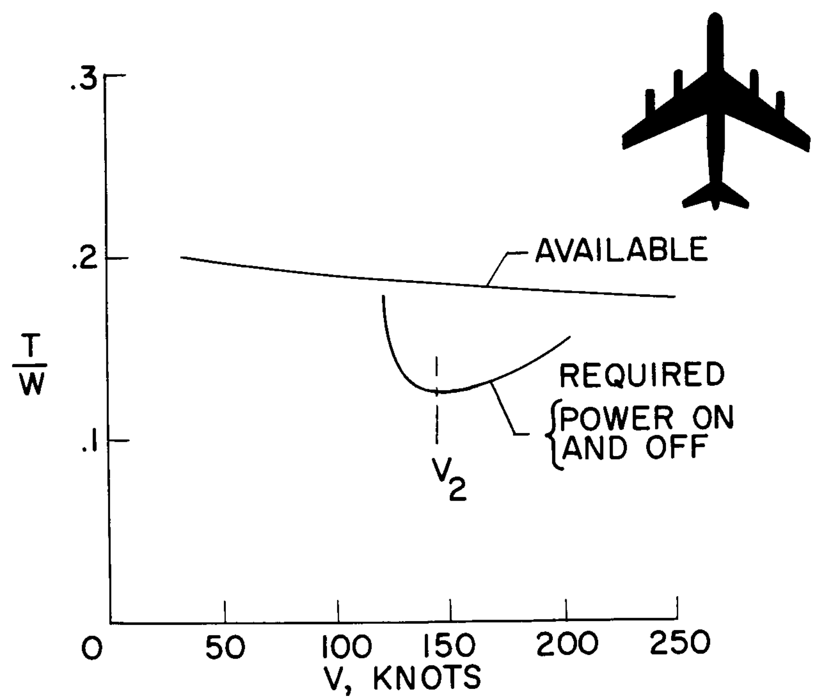

Figure 4.- Thrust variation for jet transport. Take-off condition; $\delta_f = 30^{\circ}$.

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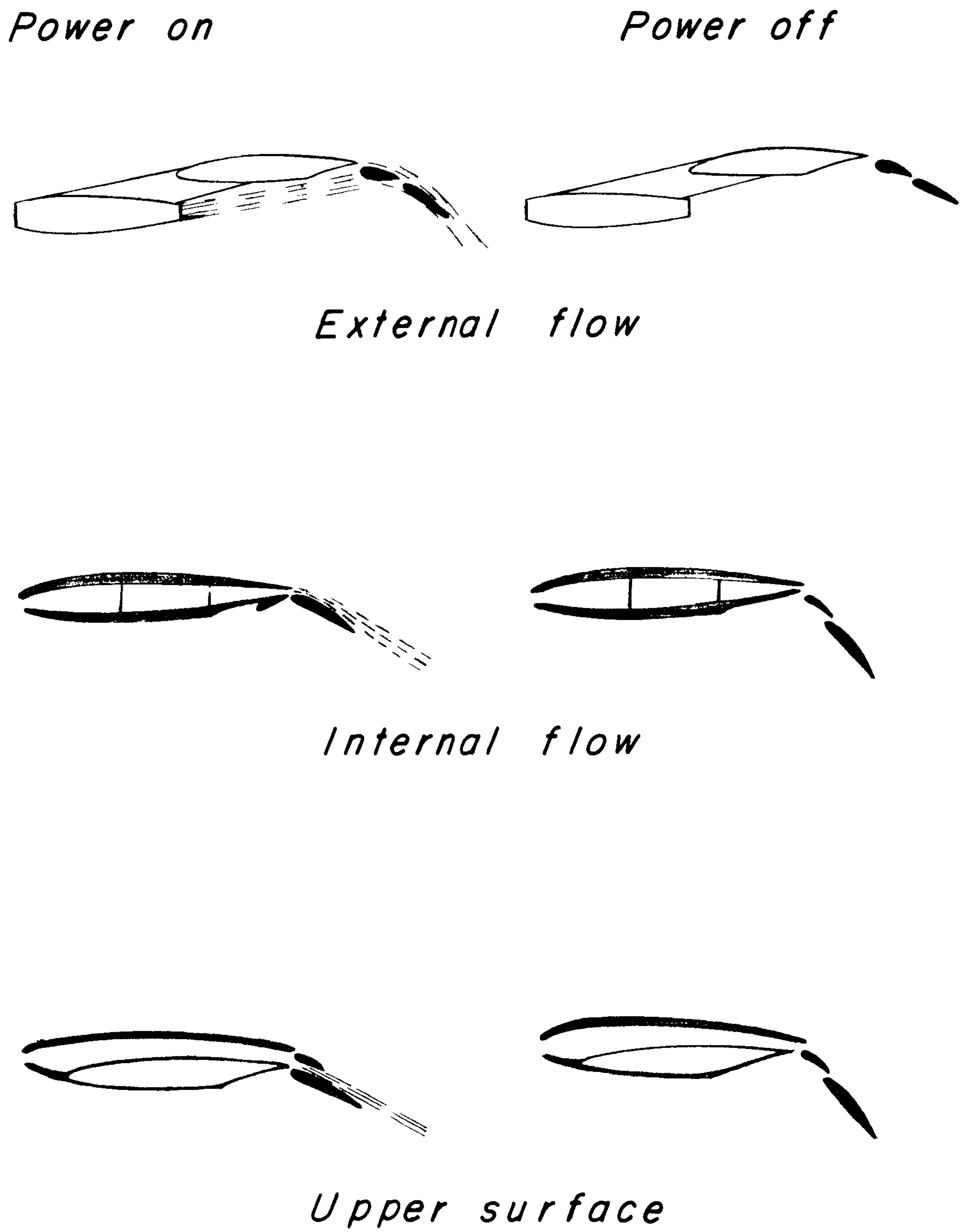

Figure 5.- Lift-augmentation systems.

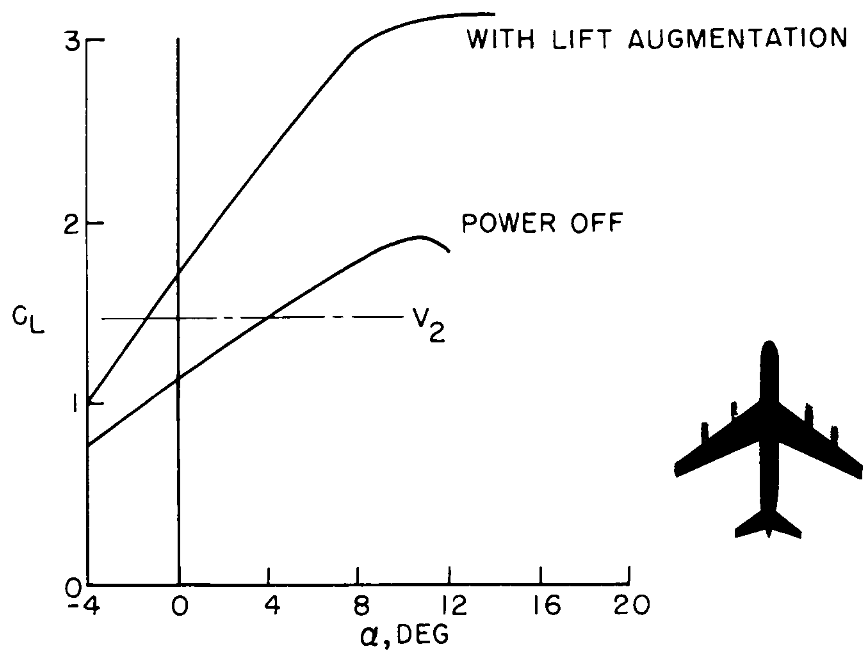

Figure 6.- Effect of lift augmentation on jet transport. Take-off condition; $\delta_f = 30^\circ$.

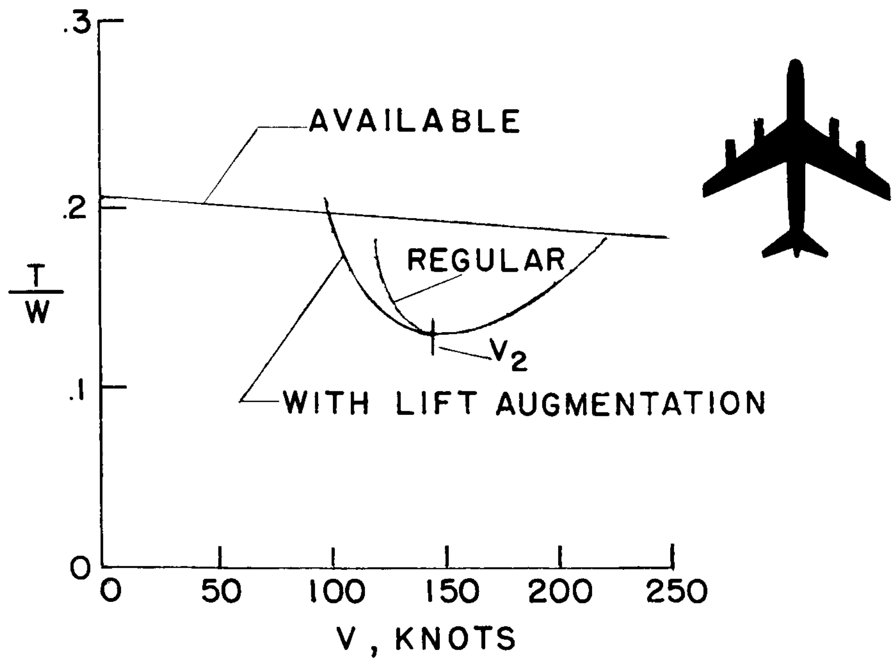

Figure 7.- Effect of lift augmentation on thrust variation for jet transport. Take-off condition; $\delta_f = 30^\circ$.

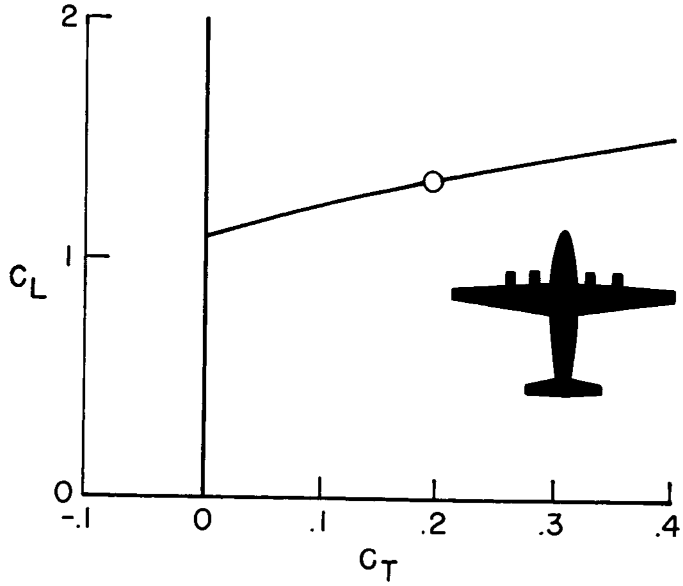

Figure 8.- Effect of thrust coefficient on lift coefficient for propeller-driven transport. Landing approach; $\delta_f = 60^\circ$; α = Constant.

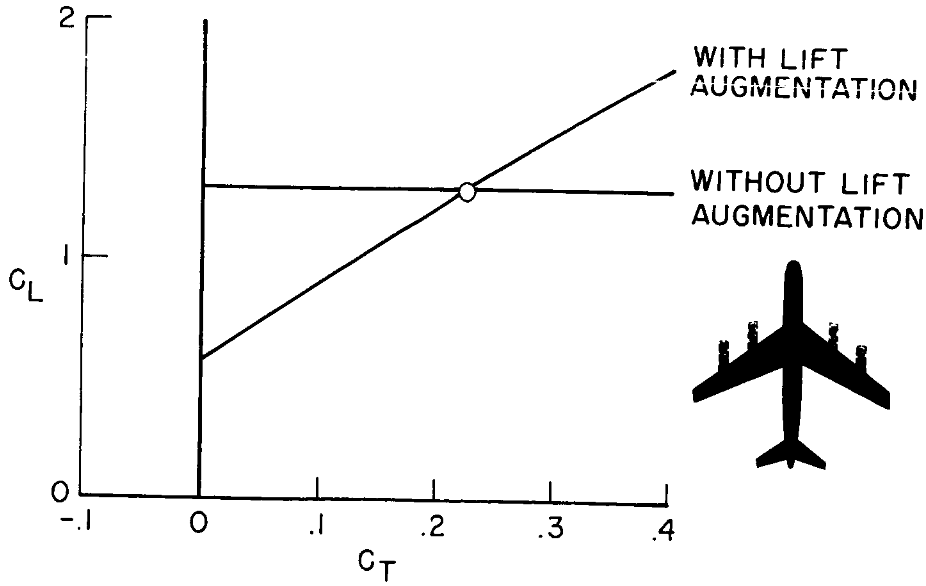

Figure 9.- Effect of thrust coefficient on lift coefficient for jet transport with and without lift augmentation. Landing approach; $\delta_f = 60^\circ$; α = Constant.